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FLIGHT-SIMULATED LAUNCH-PAD-ABORT-TO-LANDING MANEUVERS FOR A LIFTING BODY

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Abstract

The results of an in-flight investigation of the feasibility of conducting a successful landing following a launch-pad abort of a vertically-launched lifting body are presented. The study attempted to duplicate the abort-to-landing trajectory from the point of apogee through final flare and included the steep glide and a required high-speed, low-altitude turn to the runway heading. The steep glide was flown by reference to ground-provided guidance. The low-altitude turn was flown visually with a reduced field-of-view duplicating that of the simulated lifting body. Results from the in-flight experiment are shown to agree with ground-based simulation results; however, these tests should not be regarded as a definitive due to performance and control law dissimilarities between the two vehicles.

Introduction

The concept of using blunt-nosed, low lift-to-drag ratio vehicles to return from earth orbit is not new. Performing the end-of-mission landing of such vehicles was investigated in-flight almost 40 years ago^{1,2}, and consideration of the ability to perform a launch-pad abort and landing was supported by in-flight tests using appropriately configured test aircraft in the early 1960s³. The use of lifting-body vehicles to provide an assured return from the International Space Station has again been proposed in recent years^{4,5}. A logical next-step would be to use such a lifting-body vehicle as a method to ferry personnel to the Space Station as well, using existing expendable launch vehicles^{6,7}. An earlier paper describing a ground-simulator-based investigation into the feasibility of conducting a launch-pad abort for such a vehicle has been presented⁸. This paper details an in-flight investigation of a portion of the same maneuver, including a high-speed, low-altitude turn required for orientation to the runway based upon current launch site geometry.

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Limited cockpit field-of-view, especially when turns are made away from the side of the cockpit in which the active pilot is seated, make the low-altitude turn more difficult. This test included the use of blue-orange masking to simulate the restricted field-of-view available to the pilot located on the outside of the turn in the lifting body.

The purpose of this study was to perform an in-flight investigation of the feasibility of performing this abort maneuver, including the steep glide and high-speed turn to final heading, with the field-of-view restrictions of the candidate lifting-body design. This was accomplished by flying an existing high-performance aircraft with similar lift-to-drag characteristics through a portion of the abort trajectory, with restricted field-of-view, and obtaining pilot comments on the ease or difficulty of performing the maneuvers that made up the pad-abort-to-landing trajectory.

Simulated aircraft

The vehicle simulated in this study was the HL-20 lifting body design, proposed as part of the Personnel Launch System. The HL-20, shown in figure 1, was designed to transport a crew of two and up to eight passengers to and from low earth orbit. It could be launched into orbit either inside the payload bay of the Shuttle Orbiter or on an expendable launch vehicle of the Titan-IV class. Due to

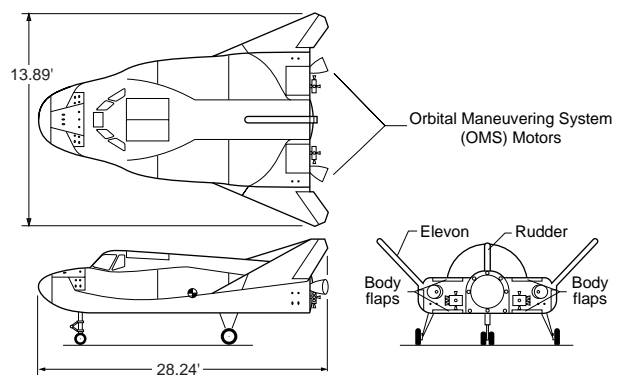


Fig. 1 - HL-20 lifting body

its relatively high lift-to-drag ratio at supersonic speeds, an HL-20 would be able to land in daylight conditions at one of several widely-spaced facilities at almost any time. The approach and landing would be an unpowered flared landing similar to that flown by the Shuttle Orbiter.

The maximum trimmed subsonic lift-to-drag ratio of this 20,000 lb. vehicle was predicted in wind tunnel testing to be 4.3. An end-of-mission landing approach was developed for a 300 kt equivalent airspeed (KEAS) approach on a -17 degree flight path angle using approximately 20% speedbrake deflection. A preflare maneuver would be performed at 1,400 feet leading to a shallow (-1.0 degree) inner glideslope and a 200 KEAS touchdown.

In addition to normal end-of-mission landings^{9,10} as well as various mid-launch abort scenarios^{4,11}, an on-pad abort scenario was studied using ground-based simulators⁸. These investigations showed that, with minor modifications to the launch-vehicle/lifting-body adapter segment, a feasible launch-pad-abort to runway trajectory could be achieved in simulation at an initial mission weight of 25,800 lbs.

The abort scenario under consideration is considered worst-case in that it represented the most distant launch pad (Kennedy Space Center pad 39A) from the landing site (Cape Canaveral Air Force Station runway 13). The scenario also included a 22-knot wind blowing from the landing site to the launch pad and a 52 degree heading change on short final approach as shown in figure 2. Depicted in the figure is the abort trajectory from pad 39A, including the turn to final and a landing on runway 13. A projection of this same trajectory is shown in planform and side views for easier understanding by the reader. Glide speed during the abort averaged 300 knots on a -14 degree glide from an apogee of 10,500 ft following a 3.5 s, eight-g launch escape system firing and 11.5 s one-g sustainer rocket firing. Target touchdown speed at the 25,800 lb abort weight was 230 knots.

Test aircraft

In order to duplicate the steep outer glideslope (prior to preflare), a Northrop T-38A twin-turbojet supersonic trainer aircraft was utilized for the flight tests (see figure 3). The T-38A has a gross takeoff weight of approximately

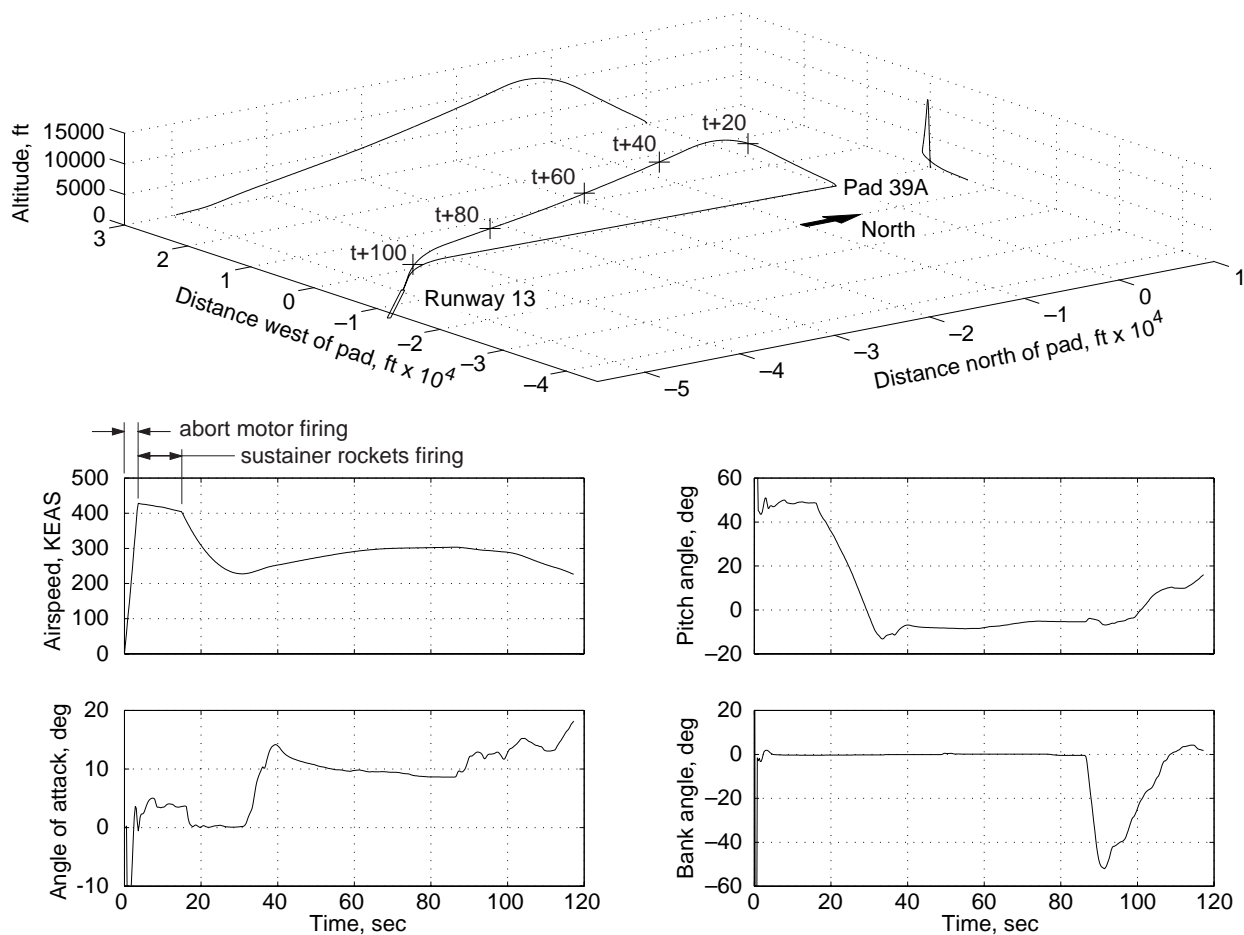


Fig. 2 - Nominal launch-pad abort trajectory

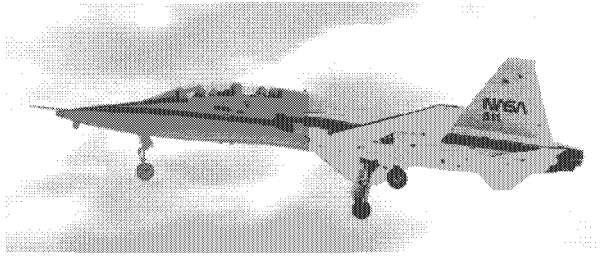


Fig. 3 - T-38A test aircraft

12,500 lb including a usable fuel load of 4,084 lb of JP-8. The T-38 has been used extensively to introduce lifting-body approaches to test pilots and as chase vehicles for the Shuttle Orbiter. By extending the landing gear and reducing throttle to idle, the T-38 was able to match the outer glideslope conditions of the HL-20 launch-pad abort approach (-14 degrees and 300 knots) at a fuel weight of 2,500 lbs.¹²

While the test aircraft could duplicate the outer glideslope performance at a given weight condition, it should be noted that once the turn to final begins, the HL-20's lower lift slope and resulting higher induced drag will cause the comparison between the two vehicles to degrade, so these tests should not be used as a definitive performance simulation.

Flight calibration

The T-38 was flown in steep descents in order to calibrate the lift-to-drag ratio at various fuel loads at the design speed of 300 knots calibrated airspeed (KCAS). For the calibration flights as well as the data flights, the vehicle was flown in stabilized flight at 300 KCAS with landing gear extended.

These calibration flights demonstrated that at a fuel load of 2,500 lbs the T-38 sufficiently matched the HL-20 in launch-pad abort outer glideslope performance.

Window masking

The abort trajectory being investigated included a steeply-banked turn to align with the runway centerline. This banking maneuver raised a question about the feasibility of performing the turn from the pilot seat on the outside of the turn, since the small windows associated with spacecraft lead to significant restrictions to field-of-view for the pilot looking across the cockpit. As described below, the candidate abort trajectory was reflected across the extended runway centerline for safety-of-flight reasons during this study and thus included a steeply-banked turn to the right.

An HL-20 full-size mockup vehicle with five cockpit windows was used as a template to develop appropriate masking for the T-38 windshield and canopy. Figure 4 shows the field-of-view of the left side pilot eyepoint through the left-center and center windows as measured in the mockup. Since the turns to final approach in the flight test experiment would be made to the right, only the forward- and right-side field-of-views were recreated in the test aircraft. Figure 5 shows the T-38A canopy with amber cellophane mask applied. When viewed through a helmet visor with blue cellophane, the amber appears opaque, as shown in figure 6, closely matching the field-of-view available to the pilot in the left-seat of an HL-20. Note, however, the intrusion of the T-38 canopy bow at the bottom of the field of view; this interference was a factor in the final landing flare. Figure 7 shows the exterior of the test aircraft with the masking applied.

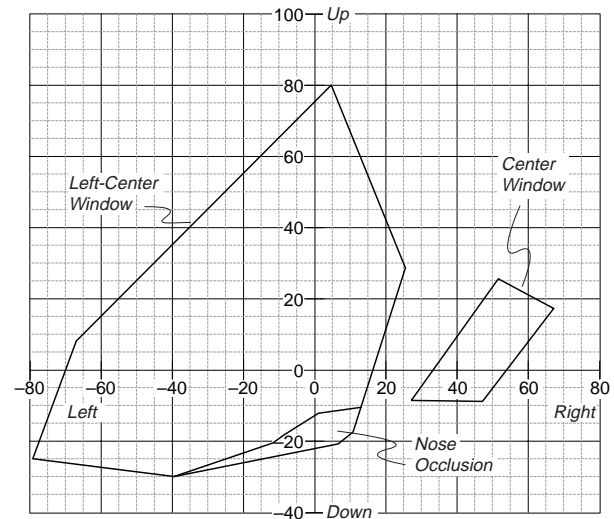


Fig. 4 - HL-20 full-size mockup left seat visibility diagram

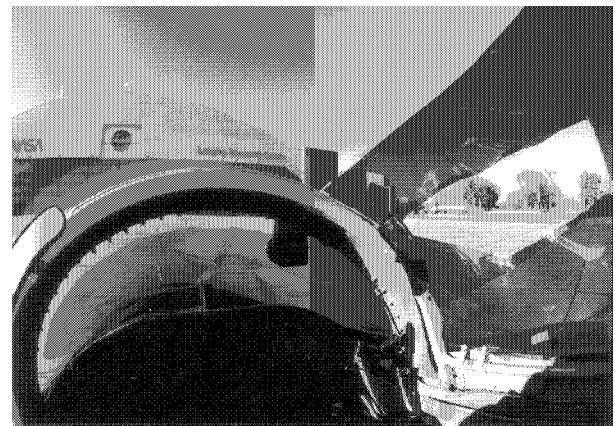


Fig. 5 - T-38 front-seat field-of-view with masking applied

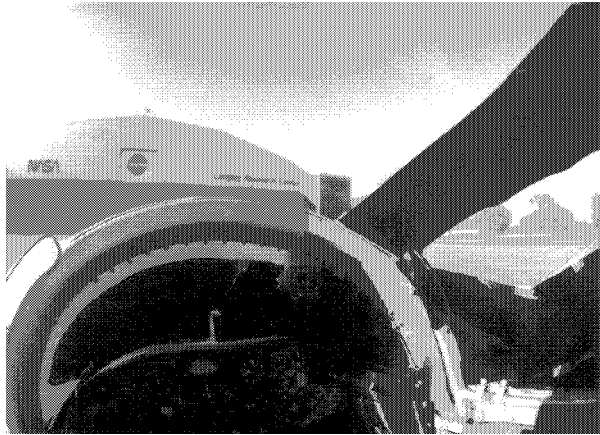


Fig. 6 - T-38 front-seat field-of-view through blue filter



Fig. 7 - T-38 exterior with masking applied

Ground tracking and guidance

The test flights were conducted at NASA Wallops Flight Facility, Wallops Island, Virginia, with approaches flown to runway 04. For safety reasons, the desired flight path was reflected about the runway centerline so that the approach would be flown from the southeast with the final turn being a right turn onto runway centerline. This insured that the majority of the maneuver would be flown over water in protected airspace. (In this paper, the trajectory data from these flights has been reflected about the runway centerline to match the original abort-to-landing geometry in which the turn was made to the left and the field-of-view restrictions would affect the right seat-pilot.)

The HL-20 spacecraft would probably carry a GPS-based navigational and guidance system to provide guidance to the pilot during a nominal or post-abort landing. The T-38A has no such system; to duplicate the trajectory in the T-38, a nominal trajectory (a mirror image to that shown in figure 2) was provided to Wallops range personnel so that deviations from the desired trajectory could be measured using ground-based radar tracking systems.

A facility unique to Wallops has the ability to provide standard Instrument Landing System (ILS) localizer and glideslope deviation signals based upon the deviation from any desired trajectory - in effect, using the production T-38 ILS system to provide guidance along the desired curvilinear flight path.

At the end of each flight, a data file containing radar-determined positions in three dimensions was made available for trajectory comparisons.

Test procedure

Flight tests were conducted on three separate days. The first two flight days, flown without visibility masking, were used to practice and refine the technique of following the ILS signals from the ground tracking radar. These runs revealed that the pilot needed some lead in order to make the turn to final without overshooting the runway centerline in the T-38A; the ground simulation included a graphical navigation display in the cockpit that provided this lead information that the T-38A with only ILS guidance did not have.

The third flight day included radio calls from the ground to provide the required anticipation of the final turn, which seemed to work out well when the turn cue was provided 1/4 mile (approximately 3 seconds) prior to the beginning of the turn. In addition, cockpit masking was included to replicate the HL-20 cockpit field-of-view. These runs were made with a safety pilot in the back seat of the T-38A.

Winds were a factor in the results of the third flight day, with winds at 10,500 feet running up to 66 knots out of the northwest (more or less directly into the approach leg), changing to 20 knots out of the west at 1000 feet (more or less a direct left crosswind in the landing flare). As a result, on the third flight day, the outer glideslope was flown at 285 knots calibrated (rather than 300 KCAS) when on the desired weight conditions (2,500 lbs fuel) to maintain the desired -14 degree flight path.

The pilot commenced the approach on a run-in line provided by radar guidance to intercept and track the initial abort trajectory course. The aircraft was configured for the desired speed with landing gear extended. On a call from the radar controller, a zero-g pushover was initiated at a point corresponding to the abort apogee, and power was reduced to idle. ILS steering was followed to stay on the initial portion of the trajectory, so this portion of the maneuver was flown heads-down. On a call from the ground, the right-hand steep turn was initiated to follow the trajectory around the 52 deg turn to final, using the ILS steering for fine corrections; this turn was flown

mostly visually once the runway was clearly in view. The pilot then completed the preflare to a shallower glideslope close-in and performed a low approach to approximately 25 ft above the runway.

The pilot provided subjective written comments regarding the difficulty of flying the outer glideslope and turn to final in the presence of window masking:

“The FOV [field of view] was very adequate for these tasks since the T-38 was still in a nose low attitude at this point and quite good visibility was available over the nose.”

However, in the final flare task (actually flown to 25 ft radar altitude), he wrote: “Line-up was never a problem even with the crosswinds. Pitch attitude control was difficult with over-the-nose visibility being marginal at best. The T-38 FOV was intentionally established under assumed worst-case conditions, and with this limitation, the task was still accomplishable. However, I feel that this is

a worst-case limit, and efforts should be made to ensure that the HL-20 shows improvements over this.” Although not rigorously defined as a flying qualities experiment, the pilot ventured an overall Cooper-Harper rating of 4 with the comment “high winds caused G/S [glideslope] energy management prob[lem]s. Landing attitude difficult to establish due to forward FOV restrictions.”

Comparison of results

Figure 8 gives time history plots comparing ground- and the most successful flight-generated trajectories. Figure 9 gives values for the mismatch between the two trajectories. As shown in figure 9, the positional match versus time is quite good after the T-38 trajectory and HL-20 merge at the beginning of the pushover at abort apogee (at 30 sec). The maximum position error remains below 600 ft throughout the outer glideslope, turn to final, and landing flare. This indicates that, if the HL-20 and T-38 were flying together, the center of gravity of the two vehicles would be within 600 ft during the simulated maneuver.

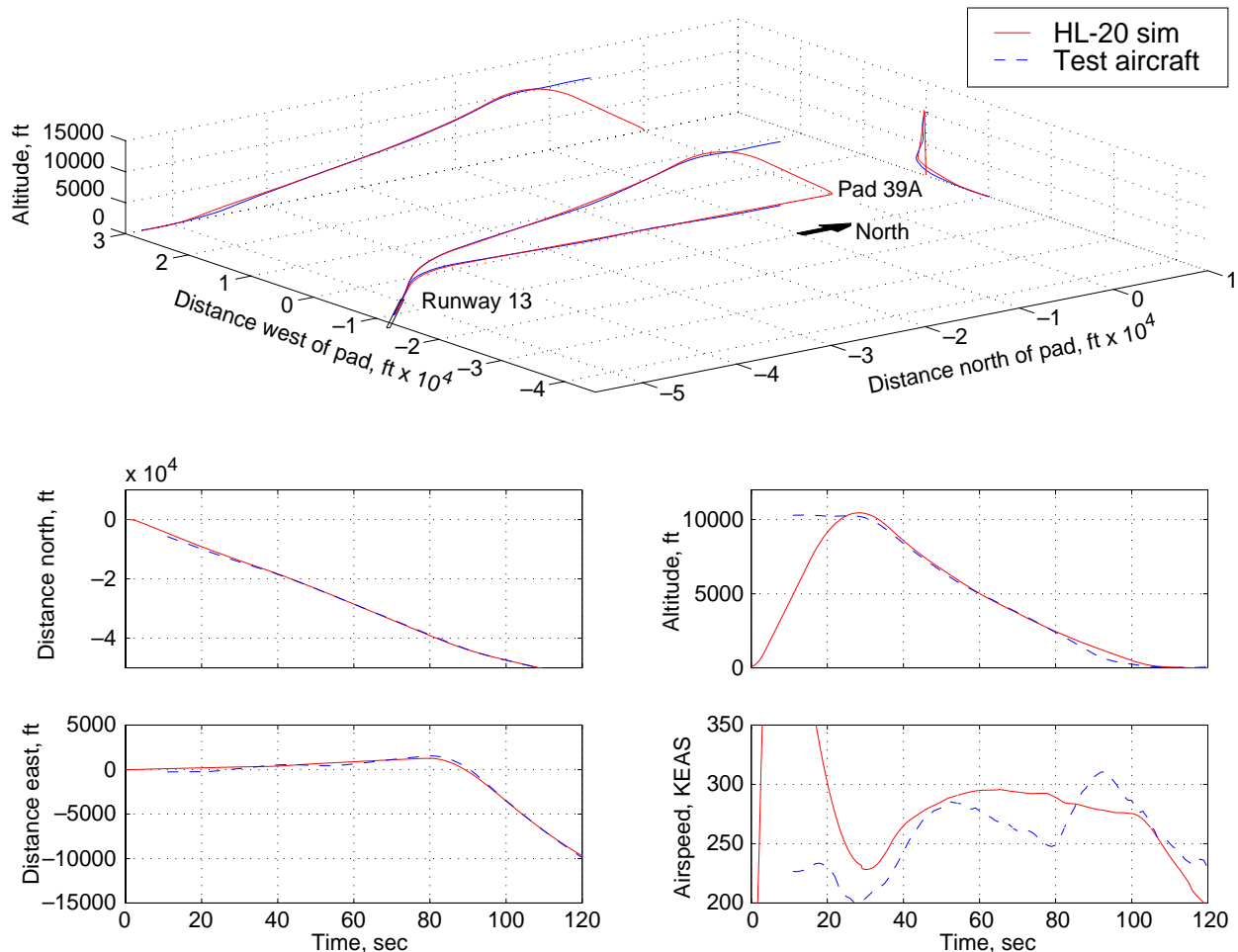


Fig. 8 - Comparison of ground simulation and flight test trajectories(best case)

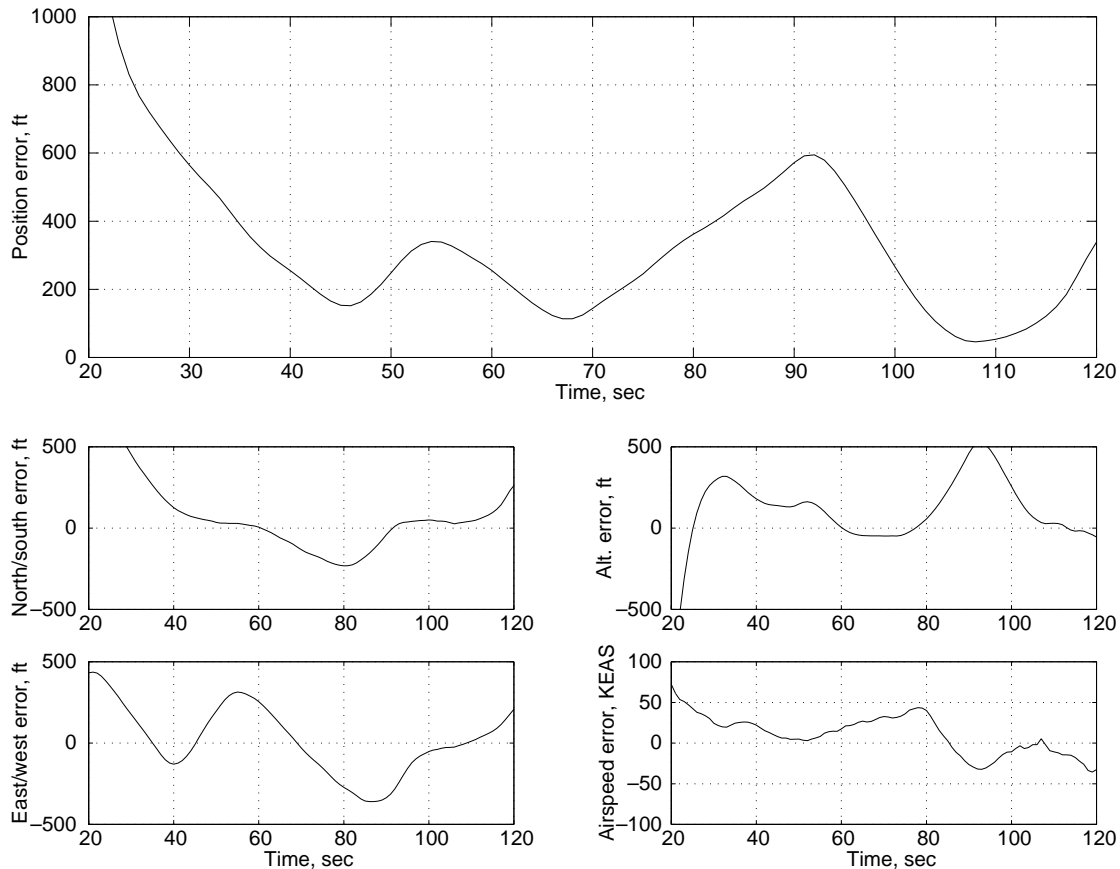


Fig. 9 - Errors between ground simulation and flight data (best case)

Velocity match seemed reasonable, with the error remaining within 50 knots, despite the strong wind shear that was present in the atmosphere. Because the T-38 had only minimal flight test instrumentation, the airspeed for the test aircraft was derived from ground tracking positional information and radiosonde data.

Concluding remarks

This flight experiment was helpful in validating the launch-pad abort landing maneuver for the HL-20, showing the maneuvering required for landing to be feasible in the presence of limitations to field-of-view. Due to differences between the test aircraft and the HL-20 these results must be considered preliminary, warranting a higher-fidelity in-flight simulation. The need to increase field-of-view over the nose of the HL-20 was identified. Finally, a useful flight test technique for duplicating steep, curvilinear approaches without sophisticated instrumentation through a unique ground radar tracking facility was demonstrated.

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